STUDY ON PERSONNEL TRANSPORT TO RESCUE SELF-ESCAPING DIFFICULT PERSONS AFTER THE TOKYO INLAND EARTHQUAKE

Satoshi KINA¹, Satoru SADOHARA², Keiko INAGAKI³, Harumi YASHIRO⁴ and Kazuaki TORISAWA⁵

ABSTRACT

The Central Disaster Prevention Council in the Japanese capital region predicts that the occurrence probability of the Tokyo Inland Earthquake is approximately 70% in the next 30 years leading to many self-escaping difficult persons due to fully destroyed buildings. For that reason, the speed at which necessary rescue personnel are mobilized to the earthquake site and are able to commence rescue activities greatly affect the number of human casualties. Therefore, preparation of a personnel transportation plan necessary for rescue activities is vital. However, details of a personnel transportation plan for the rescue of self-escaping difficult persons have not been specifically defined yet. In this paper, as a basic research, initially, the number of self-escaping difficult persons was calculated from sources related to the Tokyo Inland Earthquake in Kanagawa Prefecture. The number of necessary rescue workers was then calculated from earlier research enabled by a geographic information system (GIS) concentrating on the rescue activity base in Kanagawa Prefecture. Finally, a route from the advance base to each rescue activity base was selected considering the route risks due to earthquake ground motion.

The results of this study will include basic data for the development of life rescue activities plans for self-escaping difficult persons immediately after a disaster.

Keywords: Tokyo Inland Earthquake; self-escaping difficult person; Rescue workers transportation; seismic risk

1. INTRODUCTION

In the Great Hanshin-Awaji Earthquake and the Kumamoto Earthquake, there were a large number of “self-escaping difficult persons”, and rescue activities were requested in the emergency response period, a time when information is often confusing. “Self-escaping difficult persons” are those trapped by the collapse of houses, defined as the number of people rescued by police, fire department, self-defense forces, neighbors, or relatives, excluding those who are self-escaping.

The damage estimate of the Tokyo Inland Earthquake by the Central Disaster Management Council gave the maximum number of self-escaping difficult persons due to fully destroyed buildings by earthquake ground motion at about 72,000 in the affected areas including Kanagawa Prefecture (Central Disaster Management Council. 2013). Quick, efficient rescue response is necessary for effective results in a disaster area. Although current countermeasures specify a rescue activity base (Central Disaster Management Council Board of Directors. 2016), details such as emergency personnel transport and placement plans for rescue workers are not formulated. Hence, the scale and deployment of rescue workers to rescue activity bases is unclear. Therefore, there is a possibility that emergency response immediately after a disaster may not be implemented smoothly, thereby increasing the danger to human lives.

¹Graduate of Urban Innovation, Yokohama National University, Yokohama, Japan, kina-satoshi-bp@ynu.jp
²Institute of Urban Innovation, Yokohama National University, Yokohama, Japan, sadohara-satoru-ms@ynu.ac.jp
³Institute of Urban Innovation, Yokohama National University, Yokohama, Japan, kinagaki@ynu.ac.jp
⁴Department of Civil and Environmental Engineering, National Defense Academy, Yokosuka, Japan, hyashiro@nda.ac.jp
⁵Civil Engineering Course, Kanto Gakuin University, Yokohama, Japan, tori@kanto-gakuin.ac.jp
Miyano et al. (1996) and Murakami et al. (2001) investigated the actual situation of rescue activities in the Great Hanshin - Awaji Earthquake as a survey of self-escaping difficult persons. This study included the age of self-escaping difficult persons and the actual condition of rescue workers. Survey data on the rescue activities of the National Police Agency in the Kumamoto Earthquake were obtained through a thorough analysis of the enormous data on their rescue activities (National Police Agency. 2017). Many researchers conducted road risk assessment after the earthquake. For example, Akakura and Takahasi (1999) evaluated street blockage due to earthquakes in relation to the strength of earthquake ground motion and the width of the street. Ahmed et al. (2016) analyzed emergency transportation routes in consideration of road blockages due to collapsed buildings. These studies are useful for developing rescue activities immediately after a disaster, but do not address specifically the scope and scale of rescue workers or their route and rescue base choices.

This basic research of emergency personnel transport contributing to rescue activities in Kanagawa Prefecture focuses on self-escaping difficult persons trapped in fully destroyed buildings due to earthquake ground motion and considers the arrangement of rescue workers needed at each rescue site and their transport plan.

2. CALCULATION OF THE NUMBER OF SELF-ESCAPING DIFFICULT PERSONS

2.1 Calculation method

The number of self-escaping difficult persons was calculated using Kanagawa Earthquake Damage Assumption Survey 250-meter square grid (Kanagawa Prefecture Safety & Disaster prevention Bureau. 2015), 250-meter square grid Census Data (Population) (Ministry of Internal Affairs and Communications. 2015), and Urban Planning Basic Survey data (Building Status) (Kanagawa Prefecture Land Development Bureau. 2010). Figure 1 shows the seismic intensity distribution (250-meter square grid) of an earthquake in the Southern Tokyo Inland Earthquake used in this research. Figure 2 shows the number of fully destroyed buildings (250-meter square grid). Figure 3 shows the calculated flow of the number of self-escaping difficult persons.

Figure 1. Seismic intensity distribution of earthquake in the Southern Tokyo Inland Earthquake (Kanagawa Prefecture Safety & Disaster Prevention Bureau. 2015)

Figure 2. The number of buildings fully destroyed by earthquake ground motion in the Southern Tokyo Inland Earthquake (Kanagawa Prefecture Safety & Disaster Prevention Bureau. 2015)
Figure 3. Calculated flow of the number of self-escaping difficult persons

The population per one wooden or non-wooden (R/C and Steel frame) building was calculated using the 250-meter square grid of the 2015 census (Population) and the total floor area of residential buildings in the 2010 city planning basic investigation (Building status) data. Specifically, calculations correspond to the floor area per capita, the total floor area separated by wooden and non-wooden buildings and the number of buildings. Referencing the Basic survey of social life in 2011 (Ministry of Internal Affairs and Communications. 2011), 97.5% of residents were assumed to be at home at 5:00 in the morning and 2.5% worked outdoors. The calculation formula for the number of self-escaping difficult persons was developed with reference to the method of the Central Disaster Management Council (1), (2) and the Kanagawa Earthquake Damage Assumption Investigation Committee (3), (4).

(1) Central Disaster Management Council

\[ S_w = 0.117B_wP_w \] (1)
\[ S_n = 0.117B_nP_n \] (2)

(2) Kanagawa Earthquake Damage Assumption Investigation Committee

\[ S_w = 0.3B_wC_wP_w \] (3)
\[ S_n = 0.3B_nC_nP_{nf} \] (4)

Where:
- \( S_w \) is the number of self-escaping difficult persons (wooden) [person],
- \( S_n \) is the number of self-escaping difficult persons (non-wooden) [person],
- \( B_w \) is the number of buildings fully destroyed (wooden) [house],
- \( B_n \) is the number of buildings fully destroyed (non-wooden) [house],
- \( P_w \) is the population in building (wooden) [person],
- \( P_n \) is the population in building (non-wooden) [person],
- \( P_{nf} \) is the people stayed on the first floor in building (non-wooden) [person],
\( C_w \) is the collapse rate (wooden, cf. Equation 5) [%],

\( C_w = 0.4I - 2.1 \)  \hspace{1cm} (5)

\((I\) is the measured seismic intensity scale used by the Japan Meteorological Agency (JMA))

\( C_n \) is the collapse rate (non-wooden, cf. Table 1) [%].

<table>
<thead>
<tr>
<th>Building age</th>
<th>Before 1981</th>
<th>After 1981</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seismic intensity (JMA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 lower</td>
<td>0.8</td>
<td>0.0</td>
</tr>
<tr>
<td>6 upper</td>
<td>2.9</td>
<td>0.7</td>
</tr>
<tr>
<td>7</td>
<td>7.3</td>
<td>2.6</td>
</tr>
</tbody>
</table>

As a feature of each method, the Central Disaster Management Council (1), (2) calculates the number of self-escaping difficult persons based on the fully destroyed building (Central Disaster Management Council. 2013), whereas Kanagawa Prefecture (3), (4) calculates based on the number of collapsed buildings. In addition, Kanagawa Prefecture calculates the number of self-escaping difficult persons by using the number of people staying on the first floor in the case of non-wooden buildings (Kanagawa Earthquake Damage Assumption Investigation Committee. 2015).

2.2 Results and Discussion

Figure 4 shows the aggregate number of self-escaping difficult persons due to fully destroyed buildings using both the Central Disaster Management Council method and the Kanagawa Earthquake Damage Assumption Investigation Committee method in units of 250-meter square grid. In addition, the graph shows the top 5 results of self-escaping difficult persons for each municipality.

Figure 4. Results of calculating the number of self-escaping difficult persons by each method
On comparing the number of self-escaping difficult persons calculated by each method, we found that the number obtained by the Central Disaster Management Council method was larger than the number obtained using the Kanagawa Prefecture Earthquake Damage Investigation Committee method. The main reason for this result is that the Kanagawa Earthquake Damage Assessment Committee method estimates the number of self-escaping difficult persons from fully destroyed non-wooden building less than does the Central Disaster Management Council method. However, using either method, no major changes are noted for municipalities’ ranking on the number of self-escaping difficult persons. Meanwhile, it is necessary to consider which method results in more reliable results. After that, from the viewpoint of the safety side, rescue workers are calculated using the number of self-escaping difficult persons calculated by the method of the Central Disaster Management Council.

3. CALCULATION OF NUMBER OF RESCUE WORKERS

3.1 Calculation method

The number of rescue workers necessary to rescue self-escaping difficult persons calculated in heading 2.2 was computed with reference to the materials of the Fire and Disaster Prevention Science Center (6) (Fire and disaster management agency. 2002) and surveys relating to the police rescue activities in the Kumamoto Earthquake (7) (National Police Agency. 2017). The respective equations are shown below.

(1) Fire and Disaster Management Agency material

\[ R_t = \frac{(S_w R_{tw} + S_n R_{tn})}{T_t} \]  
\( (R = 5, T_w = 2, T_n = 4) \)  
(6)

(2) National Police Agency material

\[ R_t = \frac{(S_w R_{tw} + S_n R_{tn})}{T_t} \]  
\( (R = 8, T_w = 2.5, T_n = 5) \)  
(7)

Where:

- \( R_t \) is the number of rescue workers in total [person],
- \( R \) is the number of rescue workers per building [person],
- \( S_w \) is the number of self-escaping difficult persons (wooden) [person],
- \( S_n \) is the number of self-escaping difficult persons (non-wooden) [person],
- \( T_t \) is the rescue activity time in total [hour],
- \( T_w \) is the rescue activity time per building (wooden) [hour],
- \( T_n \) is the rescue activity time per building (non-wooden) [hour].

According to questionnaire surveys on the number of rescue workers on site by the National Police Agency, 5 or less people per rescue team was insufficient, while 10 or more people seemed excessive, therefore, it was judged about 8 people. In addition, the average time required for rescue activities in a fully destroyed wooden building was approximately 2 hours and 30 minutes. Because no survey results are available for fully destroyed non-wooden buildings in the Kumamoto Earthquake, an assumption was made that the rescue time required for these structures would be about twice that of wooden buildings. This is because rescue activities in non-wooden buildings require special equipment such as heavy machinery, while rescue activities in wooden houses are mainly manual work.

3.2 The arrangement of rescue workers to each rescue activity base

In this research, the number of necessary rescue workers in units of 250-meter square grids was counted, based on the time from their arrival at the rescue activity base to the rescue completion. Next, the nearest neighbors of rescue activity bases (86 places in total) and the center point of each cell that counted the number of rescue workers were connected based on the spatial positional relationship by GIS. This method summarizes the number of rescue workers necessary for each rescue activity base.
3.3 Results and Discussion

The number of rescue workers was calculated by using the formula in Equations 6, 7, which shows the number of self-escaping difficult persons for each rescue activity base. Figure 5 shows the number of rescue workers necessary for the number of self-escaping difficult persons determined by using the Central Disaster Management Council method. In this research, rescue workers are assumed to use 30 hours ($T_1 = 30$) of rescue activity from the time they arrive at the rescue activity base until rescue activities are completed. Also, a graph shows the top ten rescue activity bases and the number of rescue workers at each.

These research results suggest the usefulness of the advance prioritization of rescue activity bases when transporting emergency personnel and placing necessary equipment, because immediate, post-disaster information is often confusing.

![Map](image1)

(a) Calculated with reference to Fire and Disaster Management Agency material

![Map](image2)

(b) Calculated with reference to National Police Agency material

Figure 5. The number of rescue workers required for each rescue operation site
(The number of self-escaping difficult persons is based on the method of the Central Disaster Management Council)
4. SELECTION OF TRANSPORTATION ROUTES FOR RESCUE WORKERS

4.1 Selection of transportation route for rescue workers considering road damage caused by earthquake ground motion

Based on the data presented so far, transport routes for rescue workers were examined based on road damage caused by earthquake ground motion. In this research, an assumption is made that, immediately after a disaster, individual municipal rescue organizations will handle affected areas within each jurisdiction with the maximum numbers of workers. No assumption is made about any collaborations of rescue activities within the afflicted area. Selection of emergency transportation routes are made in reference to the "eight directional operation," which is the road clearing plan for a Tokyo Inland Earthquake. This research focused on the northeastern Kanagawa Prefecture where extensive damage is predicted and where transport routes of rescue teams are dispatched from outside Kanagawa Prefecture. The Kohoku service station as an advance base was used as the starting point with each rescue activity base as a destination, focusing on land transport utilizing emergency transportation routes. Figure 6 shows the target area (Tokyo Inland Earthquake Road Clearing Planning Study Council. 2016).

Figure 6. Target area
(The number of self-escaping difficult persons is based on the method of the Central Disaster Management Council)
(The number of rescue workers is based on police agency materials)

In the event of the Tokyo Inland Earthquake, rescue teams are greatly aided in efficient rescue activities of self-escaping difficult persons by selecting routes with as little road damage as possible while also being directed to rescue activity bases that need the most rescue workers. Next, using the selected route as the center axis, subsequent routes can be sequentially selected with the smallest number of damage points immediately after the disaster. This research proposes that transportation routes for rescue workers depend on the rank order of the number of rescue workers required for each rescue activity base and the smallest number of damaged places on route. The prediction for road damage caused by earthquake ground motion in Figure 7 is based on the method for estimating damage caused by the Central Disaster Management Council. (Central Disaster Management Council. 2013)

Figure 7. Calculated flow of road damage by earthquake ground motion
\[ D_p = L_s R_{d1, d2} \] (8)

Where:
- \( D_p \) is the number of damaged places in each road facility [place],
- \( L_s \) is the length of the road by seismic intensity [km],
- \( R_{d1, d2} \) is the road facility damage rate [number of damage place / km].

\( R_{d1} \) is used for national road of designated section and expressways, and \( R_{d2} \) is used for national road outside the designated section, prefectural roads, municipal roads. Table 2 shows the respective values.

Table 2. Road facility damage rate (Number of damage points / km).

<table>
<thead>
<tr>
<th>Seismic intensity (JMA)</th>
<th>Type of road</th>
<th>( R_{d1} )</th>
<th>( R_{d2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>National road of designated section, Expressways</td>
<td>National road outside the designated section, Municipal roads</td>
<td></td>
</tr>
<tr>
<td>5 lower</td>
<td>0.035</td>
<td>0.016</td>
<td></td>
</tr>
<tr>
<td>5 upper</td>
<td>0.110</td>
<td>0.049</td>
<td></td>
</tr>
<tr>
<td>6 lower</td>
<td>0.160</td>
<td>0.071</td>
<td></td>
</tr>
<tr>
<td>6 upper</td>
<td>0.170</td>
<td>0.076</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.480</td>
<td>0.21</td>
<td></td>
</tr>
</tbody>
</table>

4.2 Results and Discussion

The routes selected from the Kohoku service area of the advance base to each rescue activity base, based on the methods in Figure 7, are shown in Figure 8.

(a) Each personnel transport route selected in order of priority
Utilizing these results, it is considered that selecting rescue routes to minimize the number of damaged places based on the priority order of rescue operation bases will contribute to securing the lives of self-escaping difficult persons, and it is a basic material for rescue teams to examine efficient rescue activities. These emergency routes avoid expressways since the road risk assessment methods evaluate the risks of expressways and general national roads much more than they do prefectural roads and city roads, and their validity needs further examination. In addition, the influence of congestion and examination of alternative route selection methods when the assumed route is not accessible are research tasks for the future.

5. CONCLUSIONS

In this study, the number of self-escaping difficult persons is calculated from the total number of buildings fully destroyed by earthquake motion, assuming that a Southern Tokyo Inland Earthquake occurs at 5 o’clock in the morning. Based on the results, the number of rescue workers required for each rescue activity base is calculated, and rescue workers’ transportation routes from the advance base to each rescue activity base are selected in the northeastern part of Kanagawa Prefecture where serious damage is predicted. Routes were chosen based on the number of self-escaping difficult persons as a top priority and the risk of the number of damaged points on roads due to earthquake ground motion as a secondary consideration. The results of this study will be the basic data for considering the life rescue activities of self-escaping difficult persons immediately after a disaster. Future tasks include construction of a transportation model of rescue workers including not only land transportation but also maritime and air transportation, and a careful evaluation of road risks.

6. ACKNOWLEDGMENTS

The authors appreciate that the Kanagawa Prefectural Safety & Disaster Prevention Bureau, the Kanagawa Prefecture Land Development Bureau have provided materials, and Editage have edited this paper in English language.
REFERENCES


Fire and disaster management agency (2003). A survey study report on the wide area earthquake disaster prevention system for the 2002 Tokai earthquake, Demand quantity according to the type of disaster emergency measures and concept of calculation of supply quantity, pp 75-77.


